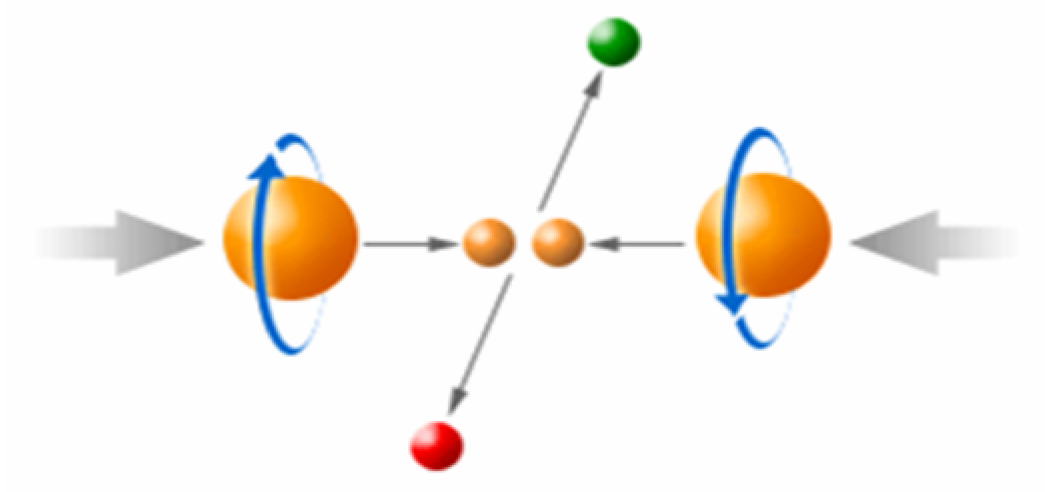
Polarization & Luminosity



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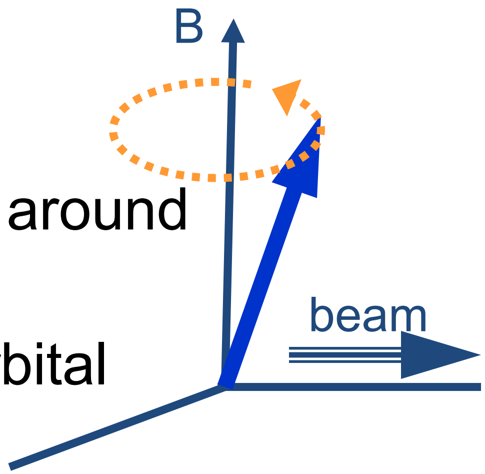
OutLine

- Introduction of spin dynamics
- RHIC polarized proton status and plans
  - luminosity
  - polarization
- Summary

Spin motion in circular accelerator: Thomas BMT Equation

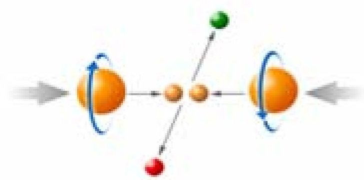
$$\frac{d\vec{S}}{dt} = \vec{\Omega} \times \vec{S} = -\frac{e}{\gamma m}[G\gamma\vec{B}_{\perp} + (1+G)\vec{B}_{//}] \times \vec{S}$$

Spin vector in particle's rest frame



- In a perfect accelerator, spin vector precesses around the bending dipole field direction: vertical
- Spin tune *Qs*: number of precessions in one orbital revolution. In general,

$$Q_s = G\gamma$$



spin depolarizing resonance

- Spin depolarizing resonance :

  coherent build-up of perturbations on the spin vector when the spin vector gets kicked at the same frequency as its precession frequency

- Imperfection resonance
  - Source: dipole errors, quadrupole mis-alignments
  - Resonance location:

$$G\gamma = k$$

k is an integer

- Intrinsic resonance
  - Source: horizontal focusing field from betatron oscillation
  - Resonance location:

$$G\gamma = kP \pm Qy,$$

P is the periodicity of the accelerator,

Qy is the vertical betatron tune

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RHIC polarization setup and depolarization mechanism

❑ To preserve polarization in RHIC:

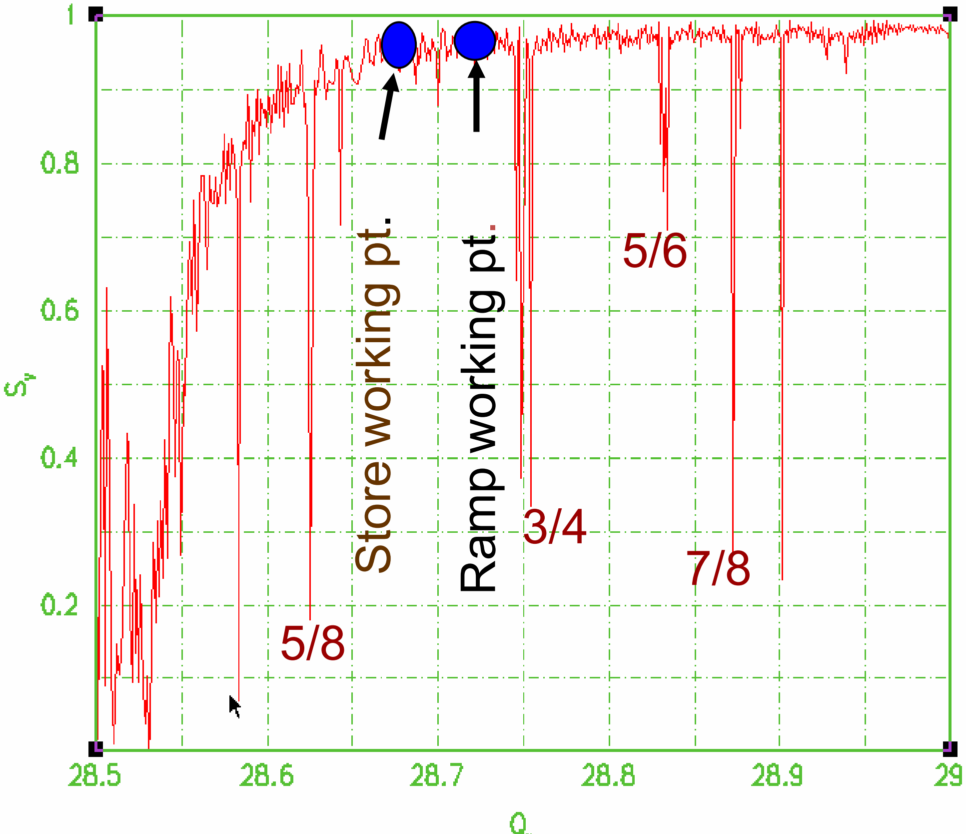
- ❑ two Siberian snakes located 180° apart forces the spin tune at 1/2, independent of beam energy.

$$Q_s = \frac{1}{2}$$

- snake error can deviate spin tune away from ½
- snake resonance is driven by the intrinsic spin resonance
- For the two snake configuration, all the snake resonances with m = even numbers are produced if the closed orbit is not perfectly flat, i.e imperfection resonance is non-zero

❑ Snake resonance

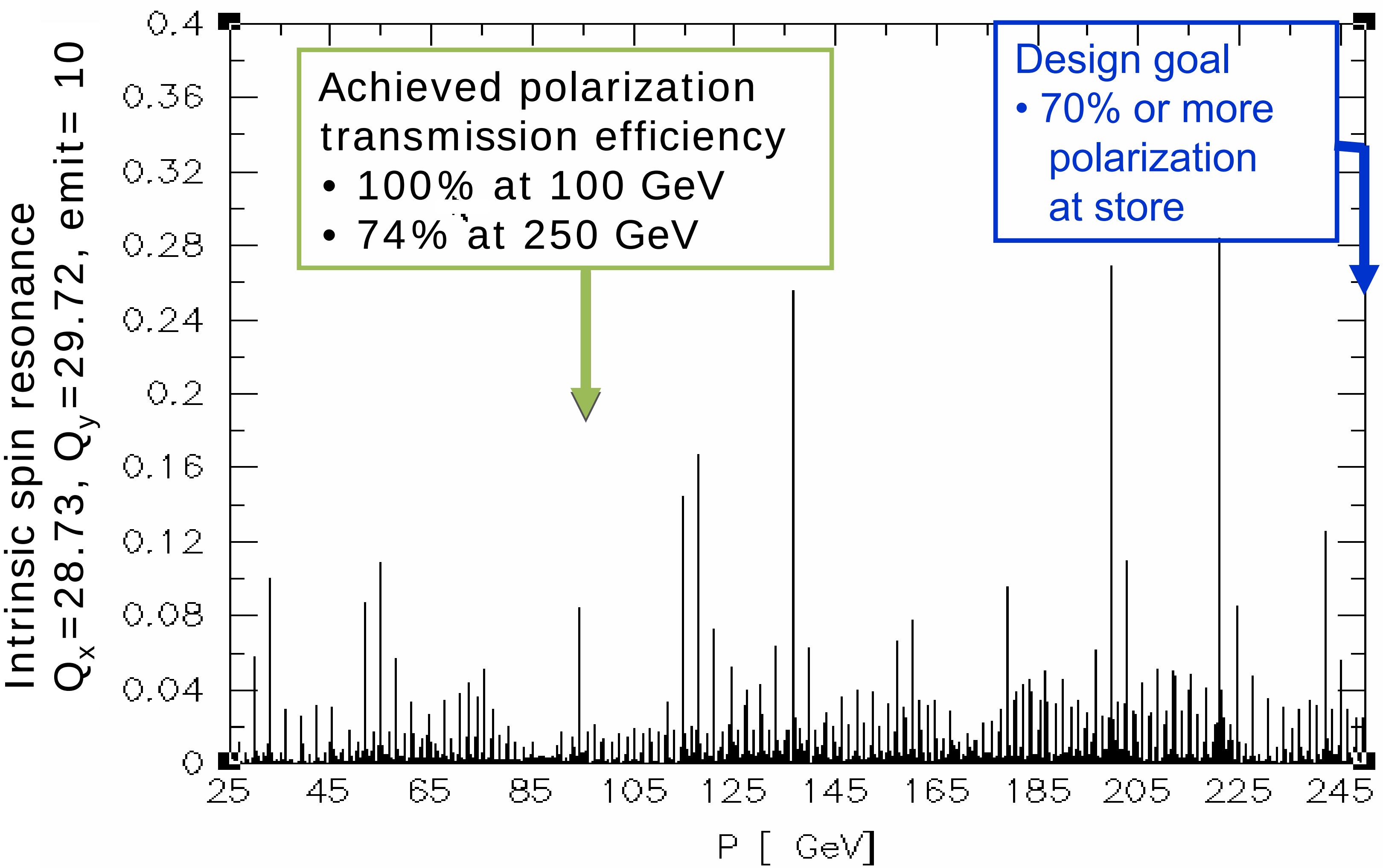
$$mQ_y = Q_s + k$$



Preserving Polarization in RHIC

- Optimize the snake setting to have spin tune at 1/2
- Precise vertical closed orbit control
  - Minimize the vertical closed orbit distortion to reduce the strength of even order snake resonances
  - For 100 GeV: rms distortion < 0.5mm
  - For 250 GeV: rms distortion < 0.3mm
- Precise optics control
  - Minimize the linear coupling
  - Keep both horizontal and vertical tune with the window where there are no harmful snake resonances
- Avoid storing the beam at an energy nearby a strong intrinsic spin resonance

RHIC intrinsic resonance spectrum



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RHIC polarized proton goal

Achieved performance

Parameter	Unit	p-p	p-p	p-p	p-p
relativistic γ, injection	…	25.9	25.9	25.9	25.9
relativistic γ, store	…	266.6	266.6	106.6	106.6
no of bunches, n_b	…	112	28	112	111
ions per bunch, N_b	10^{11}	2.0	1.0	2.0	1.3
emittance $e_{N\ x,y\ 95\%}$	mm-mrad	20	--	20	20
average luminosity	$10^{30}\ cm^{-2}s^{-1}$	150	--	20	20
polarization,store	%	70	45	70	60~65

RHIC pp luminosity goal

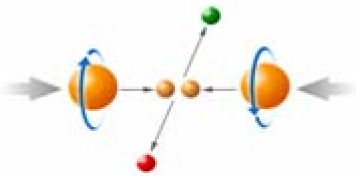
Parameter	Unit	design	achieved	design	achieved
relativistic γ, store	…	266.5	**266.6**	**106.6**	**106.6**
Bunch intensity	10^{11}	2.0	**1.0**	**2.0**	**1.3**
average luminosity	10^{30} $cm^{-2}s^{-1}$	150	**--**	**60**	**20**

- A factor of 3 is needed to achieve the luminosity goal
- where to gain the factor of 3
  - ✓ bunch intensity from 1.3×10^{11} to 2.0×10^{11} yields a factor of 2.3 contribution to the peak luminosity
  - ✓ avoid emittance growth
  - ✓ improve the luminosity lifetime

RHIC pp current luminosity issues

- Currently RHIC pp luminosity is limited by beam-beam effect
  - instant beam emittance growth right at collision limits the peak luminosity
  - continuous emittance growth during store limits the luminosity lifetime
  - A combination of beam-beam effect and a strong sextupole driven orbital resonance at 3Qx=2 causes poor beam lifetime

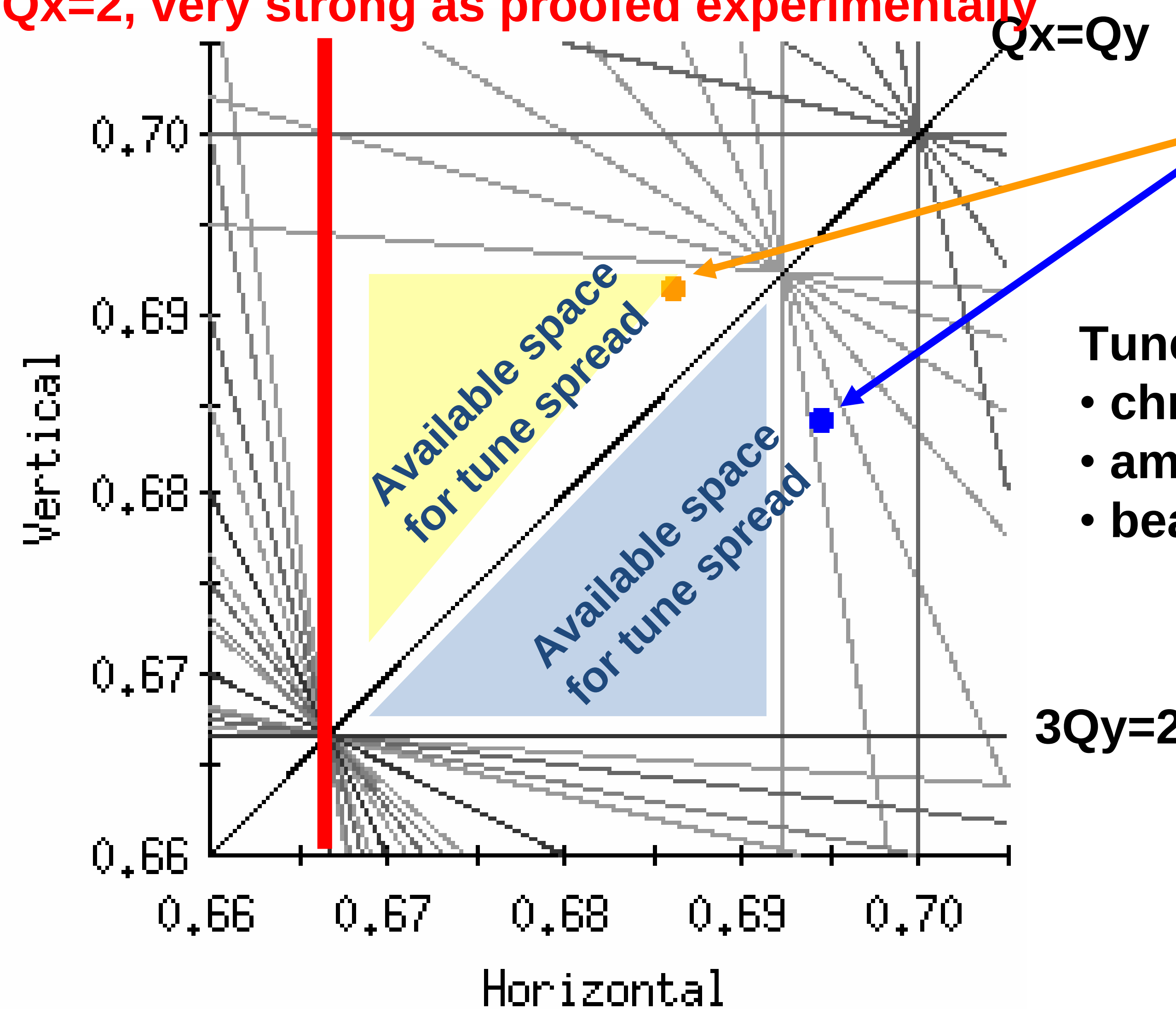
- beam-beam effect
  - Coulomb interaction between two colliding beams
  - induce additional defocusing force for proton-proton collisions
    - coherent tune shift
    - incoherent tune spread



betatron tune diagram

Orbital resonance: mQx+nQy=k

3Qx=2, very strong as proofed experimentally



Coherent beam tune (working point)

Tune spread:

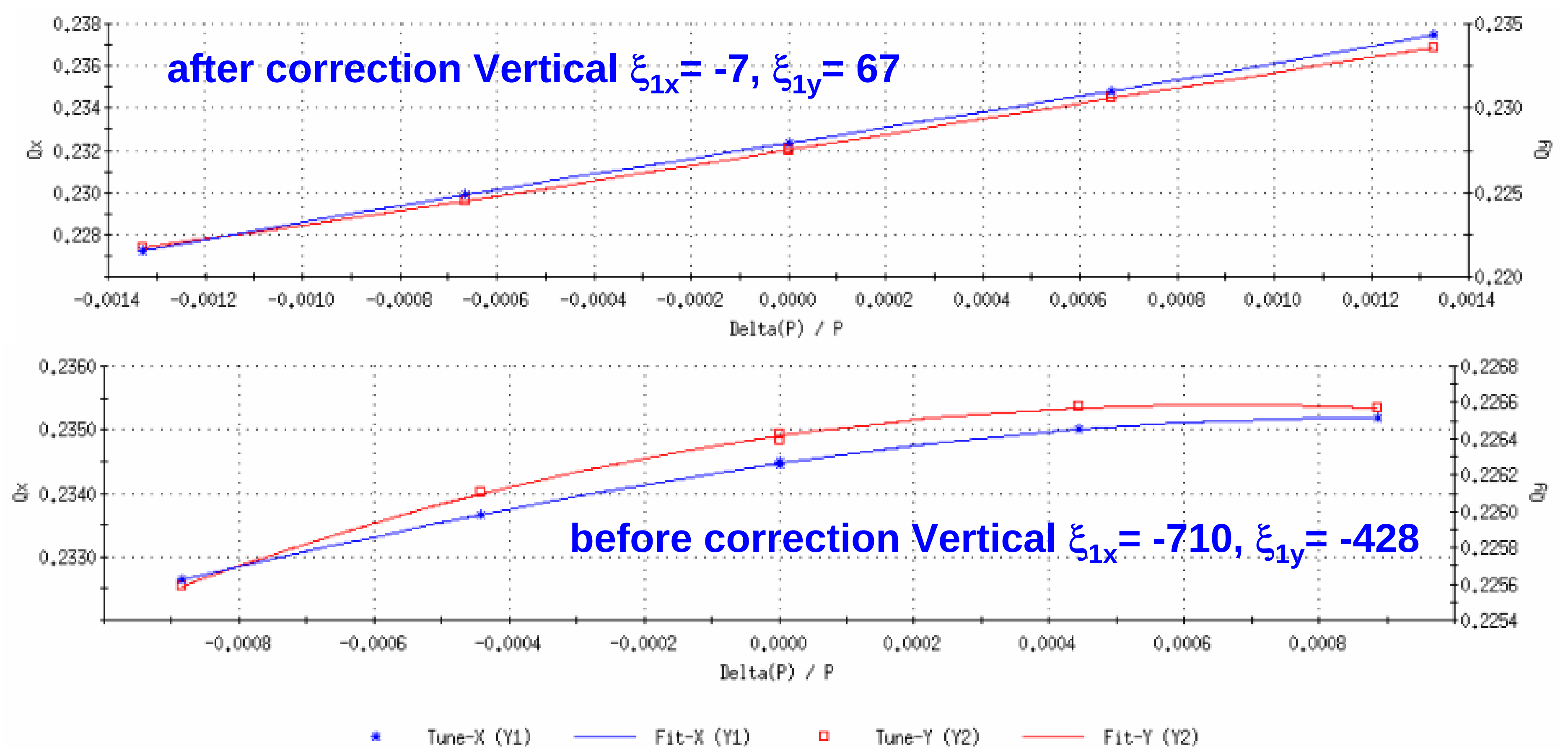
- **chromatic effect**
- **amplitude dependent**
- **beam-beam effect**

Plan for luminosity improvement

- Non-linear chromaticity correction:
  - To minimize the beam tune spread due to chromatic spread in the bunch. This effectively allows larger beam-beam induced tune spread, i.e. raise the beam-beam limit
  - Successfully implemented in the latest RHIC Au Run by S. Tepikian, N. Malitsky and Y.Luo

Non-linear chromaticity correction

$$\Delta Q_{x,y} = \xi_0 \frac{\Delta p}{p} + \xi_1 \left(\frac{\Delta p}{p} \right)^2 + \ldots$$



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Plan for luminosity improvement

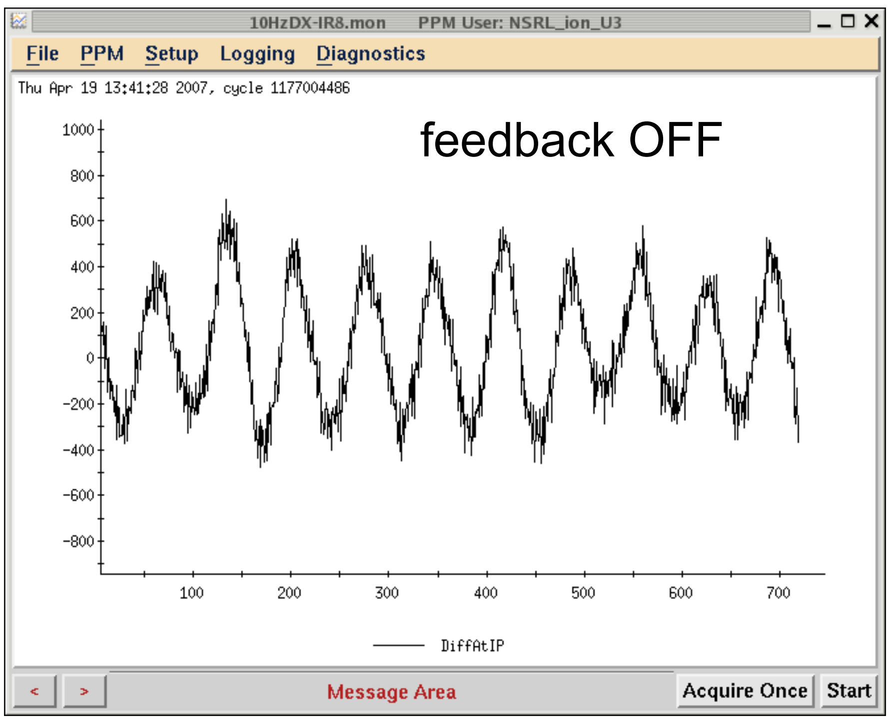
- 3Qx resonance correction:

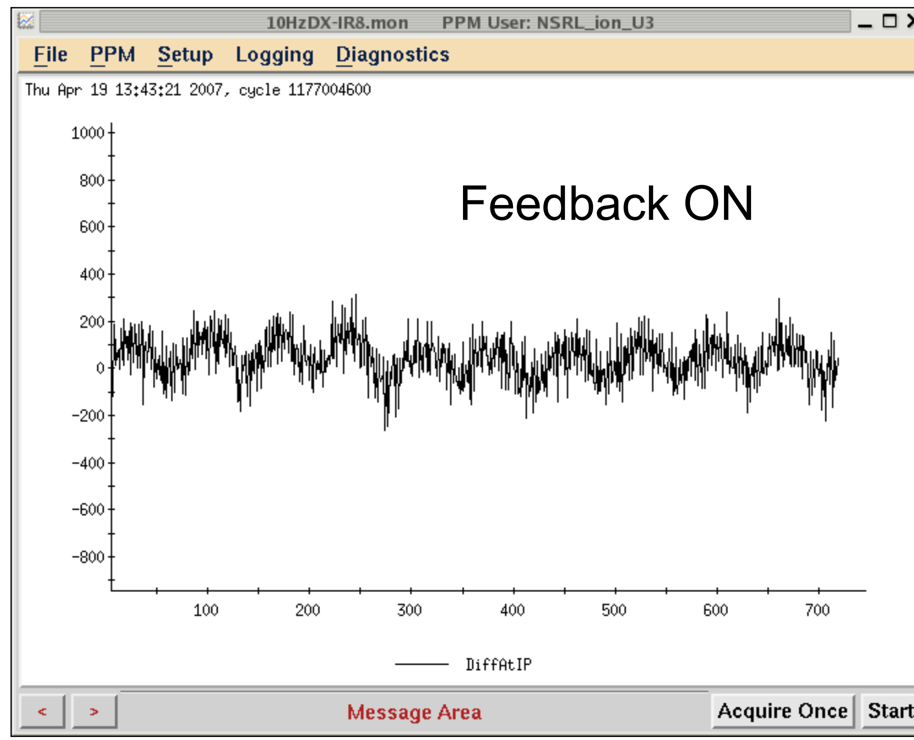
  —under study by Johan, Yun, Rama, Mei, …

- Explore new working point near integer
  - Team: <u>C. Montag</u>, W. Fischer, Y. Luo, M. Bai, A. Luccio, …
  - Tracking studies show good dynamic aperture and good spin transmission efficiency
  - Tested with Au beam during the latest RHIC Au run at injection
    - *Achieved good beam lifetime at injection at (0.04,0.03)*
    - *Able to correct the orbit at these tunes*
  - This will be first commissioned during the Run 8 pp 100GeV run

Plan for luminosity improvement

- Mitigate triplet 10 Hz vibration problem
  - Commissioned 10 Hz orbit feedback during latest Au run
  - Investigating solutions of rebuilding triplet assembly to reduce the 10Hz





Courtesy of Christoph and Angelika

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Plan for luminosity improvement

- better longitudinal match using 9MHz cavity
  - M. Brennan, M. Blaskiewicz
  - Avoid longitudinal mis-match which will help to achieve shorter bunch length at store
  - Also mitigate the emittance growth due to electron clouds because this technique avoids the problem of squeezing the bunch too short

Plan for luminosity improvement

❖ For 250 GeV, β* squeeze below 1.0m

Bunch intensity

$$L(t) \propto N \frac{n_{blue} n_{yellow}}{\sqrt{\varepsilon_{blue}\varepsilon_{yellow}}} \frac{1}{\sqrt{\beta^*_{blue}\beta^*_{yellow}}}$$

\# of bunches in collision

– Successfully squeeze β* at Phenix from 0.85m to 0.65m during the latest Au run

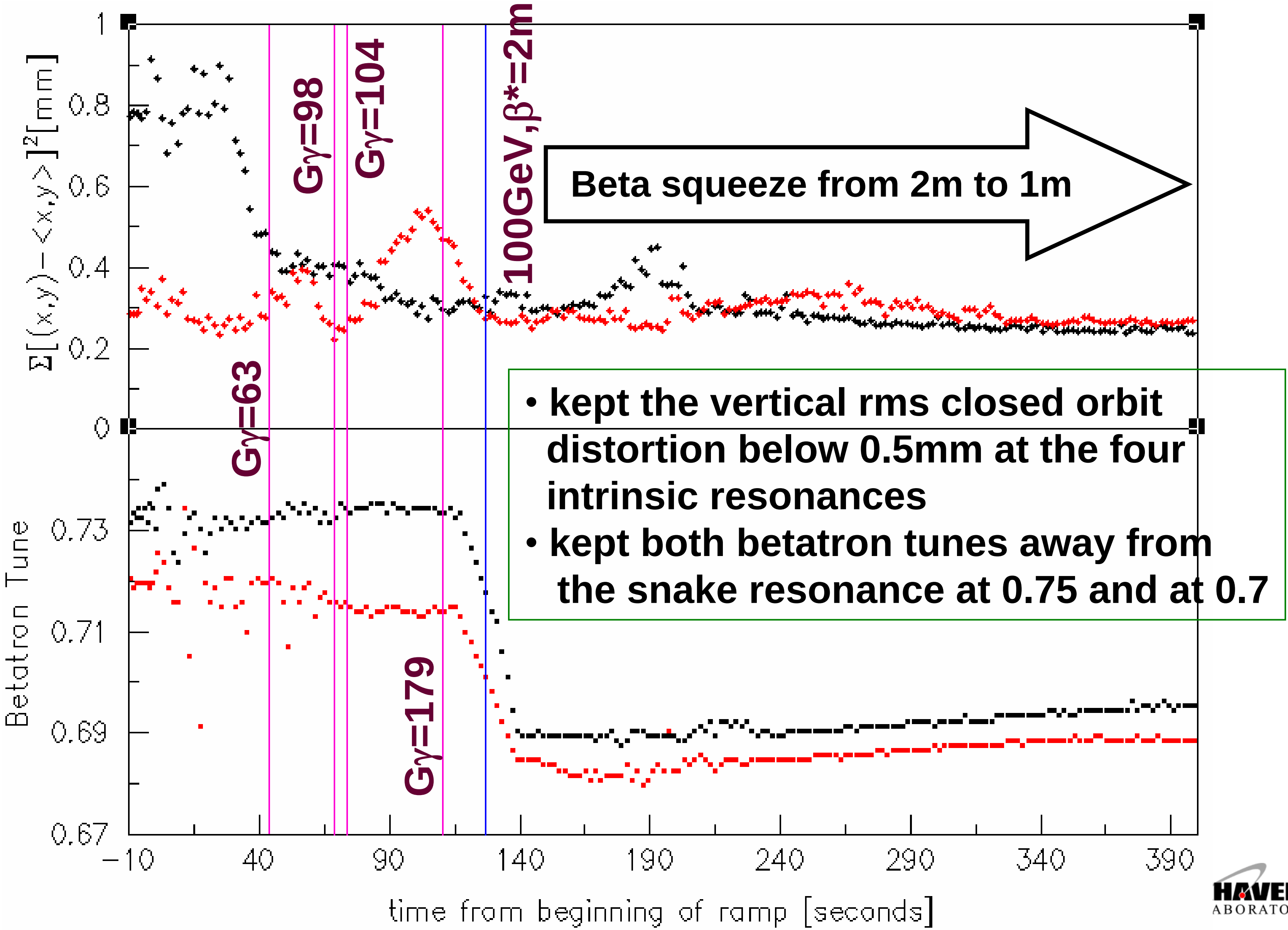
- <u>F. Pilat</u>, N. Malitsky, S. Tepikian, T. Satogata …

RHIC polarization goal

Parameter	Unit	design	achieved	design	achieved
relativistic γ, store	…	266.5	**266.6**	**106.6**	**106.6**
Average store polarization	%	70	**45**	**70**	**60**

- For 100 GeV, RHIC achieved 100% polarization transmission efficiency during acceleration and beta squeeze. Polarization was also preserved at store
- For 250 GeV, 73% polarization transmission efficiency was obtained during the first successful 250 GeV ramp

Achieved tune and orbit during RHIC 100 GeV ramp



RHIC polarization improvement

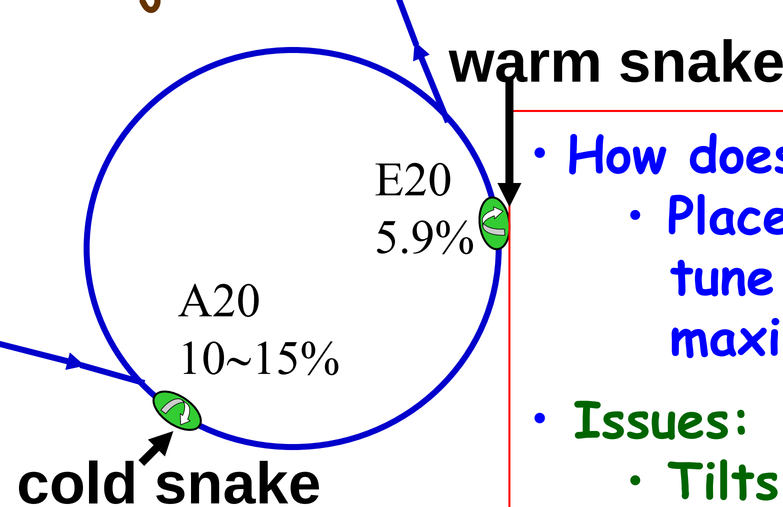
Parameter	Unit	design	achieved	design	achieved
relativistic γ, store	…	266.5	**266.6**	106.6	**106.6**
Average store polarization	%	70	**45**	70	**60**

- For 100 GeV, requires more than 70% beam polarization out of the AGS to achieve the polarization goal

	Polarization setup	Energy [GeV]	Int $[10^{11}]$	pol[%]	source pol [%]
2006	warm snake +10% cold snake vertical tune > 8.98 horizontal tune < 8.8	23.8	1.5	60~65	82~86

Polarized proton in the AGS

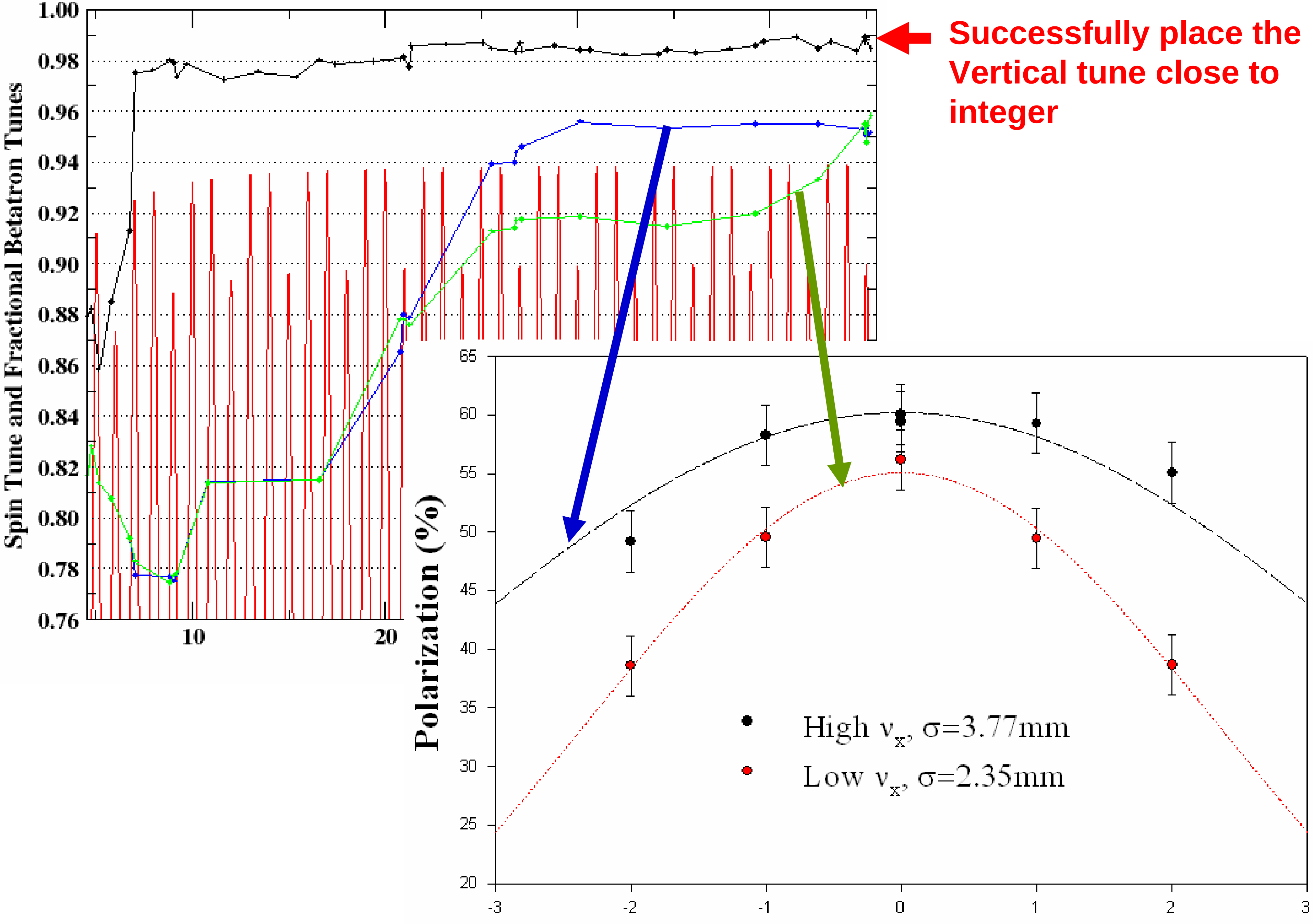
- Energy: 2.3 GeV ~ 23.8 GeV
- A total of 41 imperfection resonances and 7 intrinsic resonances from injection to extraction



- How does duel-snake work:
  - Place the vertical betatron tune in the spin tune gap with a size of 0.05~0.1 and reaches maximum at all the strong intrinsic resonances
- Issues:
  - Tilts the spin direction away from vertical. This makes the spin motion sensitive to the horizontal betatron motion
  - Induces a total of 82 weak horizontal spin resonances at $G\gamma=k\pm Qx$ and results in a total of 6% polarization loss

AGS polarized proton status

- Achieved high bunch intensity proton beam with vertical betatron sitting as high as 8.99 through the energy ramp
- AGS FY07 polarized proton run shows that high horizontal tune in the spin gap helps to mitigate the horizontal spin resonance effect
- Both AGS FY06 run and FY07 run observed polarization loss between AGS injection and $G\gamma=7.5$
  - ✓ significant lower acceleration rate at the beginning of the acceleration ramp due to the AGS main magnet power supply limit
  - ✓ additional depolarization mechanism
    - the helical snake field
    - others



Successfully place the Vertical tune close to integer

Courtesy of H. Huang

AGS polarization improvement

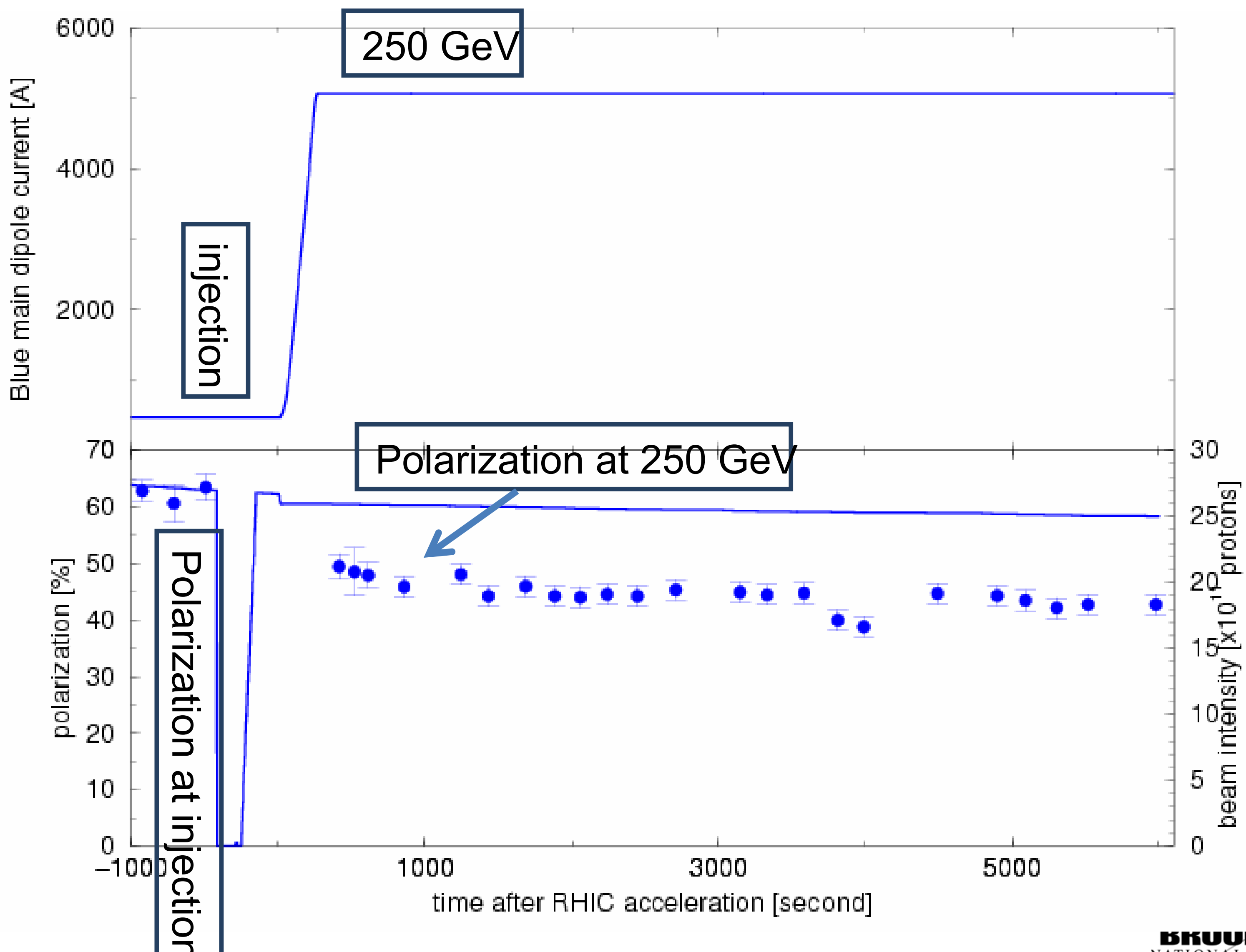
- To achieve more 70% polarization in the AGS
  - more polarization from the source ~ 90%
  - increase the AGS polarization transmission efficiency
    - keep horizontal tune high in the spin tune gap
    - injection on the fly. This will avoid
      - any possible depolarization due to the weak spin resonances because of the extra time at injection
      - keep vertical tune in the gap from injection
    - offline studies to understand the depolarization mechanism at low energy

RHIC polarization goal

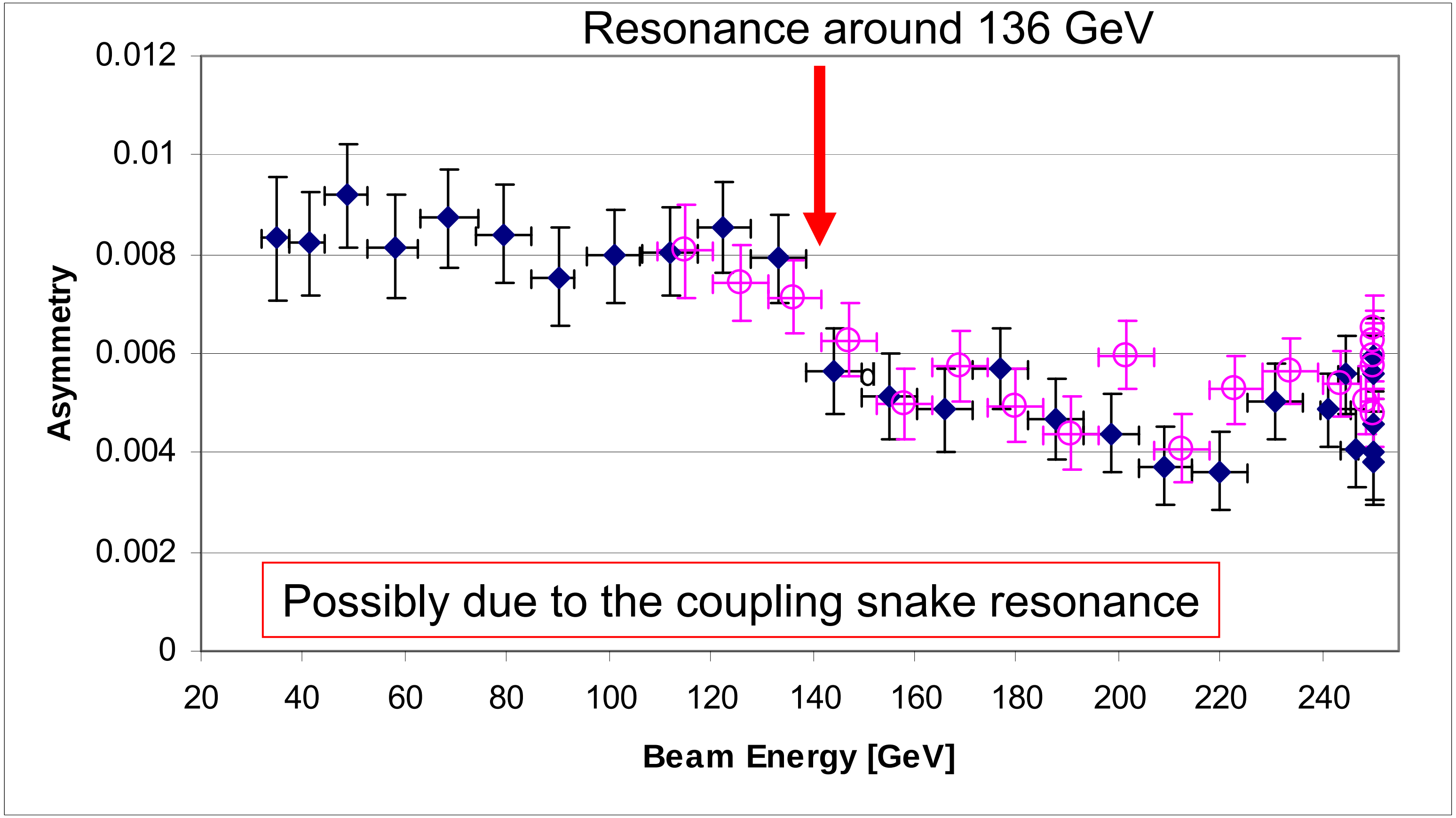
Parameter	Unit	design	achieved	design	achieved
relativistic γ, store	…	266.5	**266.6**	**106.6**	**106.6**
Average store polarization	%	70	**45**	**70**	**60**

- For 250 GeV, the one-week development in RUN 06 achieved
  - significant polarization at 250GeV in the blue ring
  - identified polarization loss at $G\gamma$=3x81+(Qy-12), or 136 GeV

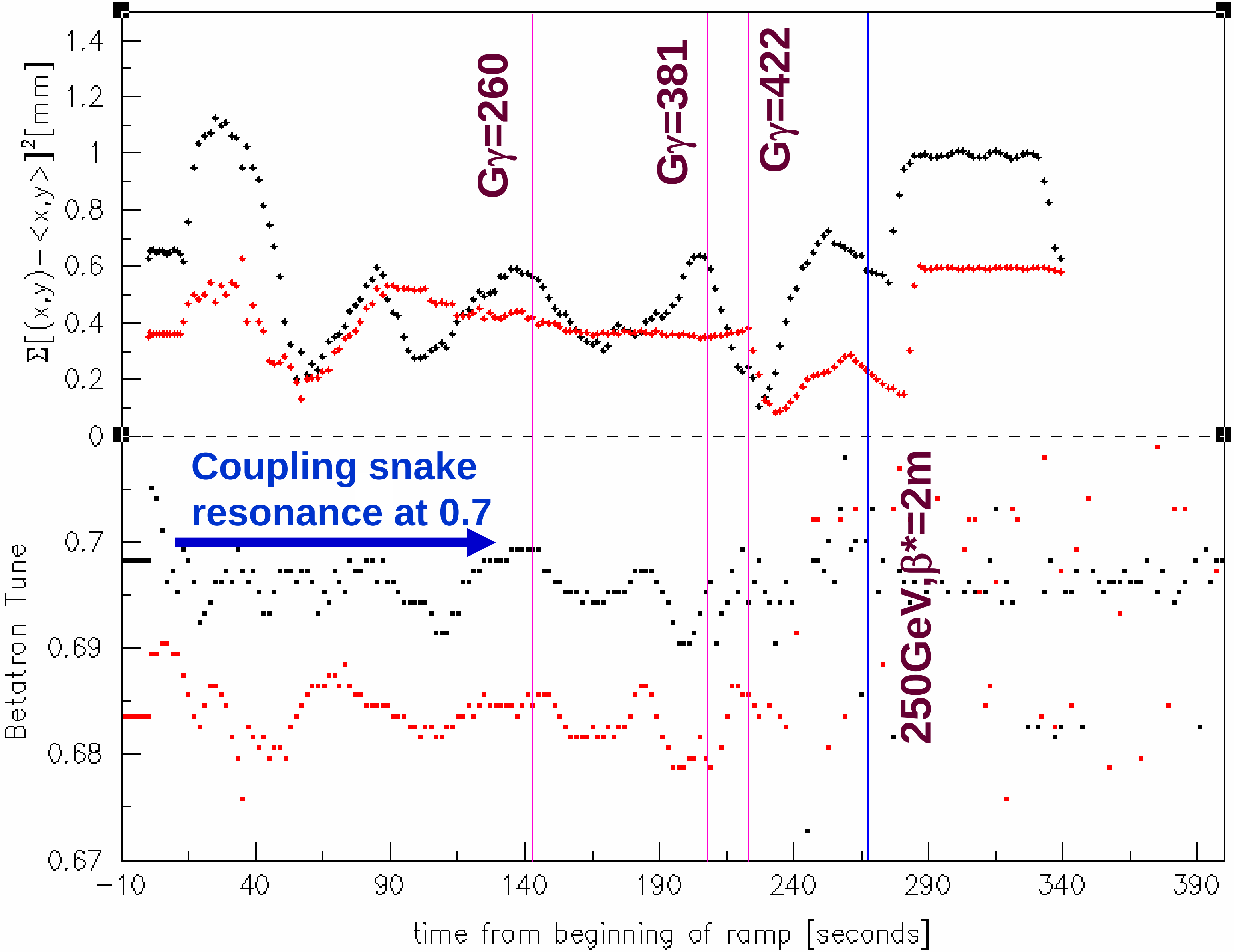
Polarized proton at 250 GeV



RHIC pp polarization ramp measurement



Achieved tune and orbit of RHIC 250 GeV ramp



Polarization improvement

Parameter	Unit	design	achieved	design	achieved
relativistic γ, store	…	266.5	**266.6**	**106.6**	**106.6**
Average store polarization	%	70	**45**	**70**	**60**

- At 100 GeV, requires more than 70% beam polarization out of the AGS to achieve the polarization goal
- For 250 GeV,
  - improve closed orbit control to <0.3mm
  - improve the tune/coupling control, keep both horizontal betatron tune and vertical betatron away from any snake resonances
  - optimize the snake current

Summary

❑RHIC polarized proton status

- At 100 GeV, achieved 1/3 enhanced design luminosity with an average polarization of 60% at store
- The first effort of accelerating polarized proton beam to 250 GeV achieved a polarization of 45%
- The polarization as a function of beam energy during the acceleration shows the polarization loss at beam energy of 136 GeV, a strong resonance at $G\gamma=3\text{x}81+(Qy-12)$

Summary

❑RHIC polarized proton plans

- Luminosity improvement
  - ➢Non-linear chromaticity correction
  - ➢Split the working point between the two RHIC rings. Move one to the near integer working point while remain the other one at the present working point at (0.695,0.685).
  - ➢Correct the sextupole driven orbital resonance at $3Q_x=2$
  - ➢For 250 GeV, further squeeze the β^* below 1m

Summary

❑Polarization improvement

- More polarization from the source -> 90%
- Improve the AGS polarization to 70% and above
  - ➢Offline analysis and study to understand the depolarization mechanism at low energy as observed during the FY07 run
  - ➢Keep the horizontal tune above 8.9 in the spin tune gap
  - ➢Injection on the fly
- Improve the polarization transmission efficiency in RHIC beyond 100 GeV
  - ➢Improve the orbit control
  - ➢Improve the tune/coupling control
  - ➢Optimize the snake current setting

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